An Augmented Reality Display for 6-DoF Task Specification During Upper-Limb Robot-Mediated Rehabilitation

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Introduction: Effective upper-limb rehabilitation after stroke requires intensive, task-specific training; however, many current robotic systems constrain therapy to low-dimensional tasks due to mechanical complexity and interface limitations [1, 2]. Despite the availability of 6-degree-of-freedom (6-DoF) industrial collaborative robots (cobots), applications often rely on simplified trajectories and external 2D displays, which can limit the range of functional movements and the intuitiveness of interaction [3]. This limitation was reflected in our own previous work, in which users were guided through prescribed trajectories on our own 6-DoF end-effector OpenRobotRehab platform [4] by controlling an avatar on a 2D screen. We noted that both healthy and post-stroke users often exerted variable motions in directions that were underspecified (e.g., into and out of the screen), rendering data less interpretable and difficult to compare across users.

Augmented reality (AR) technology offers a solution to improve interaction with high-DoF systems by providing spatially accurate visualizations in all movement dimensions. In this work, we augment the OpenRobotRehab platform with an AR-capable head-mounted display (HMD) to enable the visualization and execution of full-DoF rehabilitation trajectories.

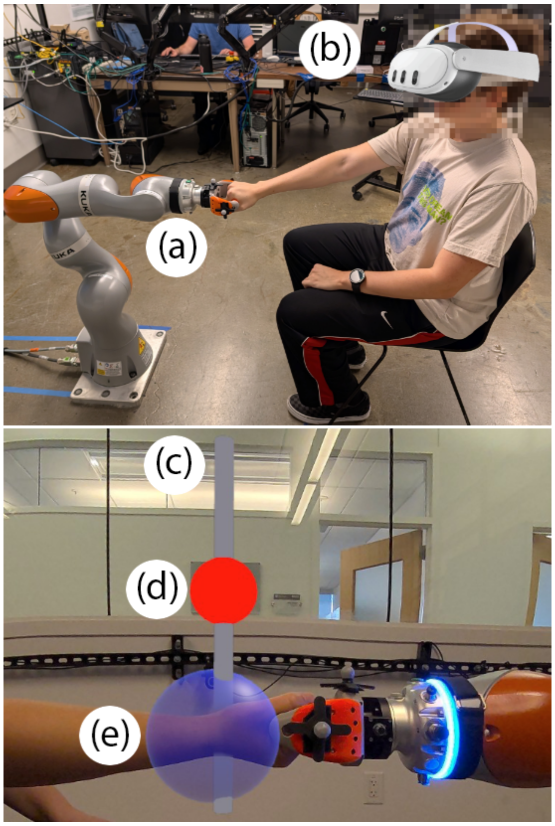

Figure 1: OpenRobotRehab platform [4] (a) augmented with Meta Quest 3 head-mounted display (b), as viewed externally (*top*; superimposed headset for anonymity) and through the headset (*bottom*). Robot joint state information is streamed to the headset via ROS 2, enabling 3D display of trajectories (c) and targets (d) to be executed by user (e) during therapy exercise.

Methods: The OpenRobotRehab platform, consisting of a KUKA LBR iiwa 14 R820 7-DoF cobot coupled with force torque and other sensing modalities, was augmented with a Meta Quest 3 HMD to provide AR visualization of prescribed end-effector trajectories within the cobot's physical workspace, as shown in Figure 1. Robot joint state and kinematic data are published over ROS 2, enabling real-time monitoring of the robot's pose. This information is streamed to a Unity-based application via the Unity ROS TCP Endpoint, which bridges ROS 2 messages into the Unity game running on the HMD. Within the game, a virtual kinematic model of the cobot is reconstructed and spatially aligned with its physical counterpart. Rehabilitation trajectories are rendered as 3D paths overlaid on the workspace using the HMD's video passthrough. This approach allows users to follow spatially complex trajectories involving translational motion across all three axes, extending beyond the planar or single-joint movements common in existing systems. The modular design of the system further supports flexible trajectory definition, synchronized data logging, and future integration of additional sensing modalities.

Results & Discussion: The implemented system supports real-time visualization and execution of 6-DoF rehabilitation trajectories. Robot joint state data stream to the headset with low latency, facilitating accurate spatial alignment and synchronized data logging. This integration demonstrates that industrial-grade hardware and consumer-grade AR displays can be effectively bridged to create high-fidelity, multi-DoF rehabilitation environments.

Significance: Our proof-of-concept AR visualization system will facilitate the development of robot-mediated rehabilitation that incorporates spatially complex tasks that more closely resemble functional activities of daily living while remaining precisely specified and characterized, enabling in-depth quantitative analysis. More broadly, this system provides a scalable foundation for future research into immersive rehabilitation interfaces and high-dimensional motor training.

In addition to the importance of task-specific practice, patient engagement is thought to be a primary driver of recovery, with higher levels of active participation closely associated with improved functional outcomes [5]. Immersive visualization has been shown to reduce cognitive load and improve embodiment during complex spatial tasks [6], further supporting its potential utility in robot-assisted therapy.

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